UNIVERSITY OF ILLINOIS BULLETIN
Vol. V. MARCH 1, 1908 No. 16
[Entered Feb. 14, 1902, at Urbana, Ill., as second class matter under Act of Congress July 16, 1894]

BULLETIN NO. 21

TESTS OF A LIQUID AIR PLANT

BY

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UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

URBANA, ILLINOIS
PUBLISHED BY THE UNIVERSITY

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Printed May, 1908.

UNIVERSITY OF ILLINOIS

ENGINEERING EXPERIMENT STATION

BULLETIN NO. 21 MARCH 1908

TESTS OF A LIQUID AIR PLANT

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The tests were made in the Mechanical Engineering Laboratory of the University of Illinois for the purpose of determining:

(a) The most economical conditions for operating the liquid air plant belonging to the departments of Physics and Mechanical Engineering.

(b) The power consumed and the cost of production of liquid air in plants of this type.

(c) The efficiencies of the separate units composing the plant.

(d) Incidentally, the keeping properties of liquid air in Dewar bulbs of different sizes, mirrored and unmirrored, enclosed in felt receptacles and open without covering of any kind.

DESCRIPTION OF APPARATUS

Fig. 1 is a diagrammatic sketch of the plant. It includes a four-stage high-pressure air compressor built by the Norwalk Iron Works, compressing up to 4000 pounds to the square inch. (See Fig. 2). The cylinders of the compressor, four in number, are arranged two in tandem, the first and third, second and fourth, and placed side by side on the bed plate. The dimensions of the compressor are: cylinders $7\frac{1}{4} \times 3\frac{3}{8} \times 2 \times 1 \times 8$-in. stroke. The rated speed is 180 r. p. m. and the capacity 17.5 cu. ft. of free air per minute delivered. Between each compressor cylinder and the next higher cylinder an intercooler is placed, through which the air passes and in which the heat due to the compression is partly abstracted by circulating water.

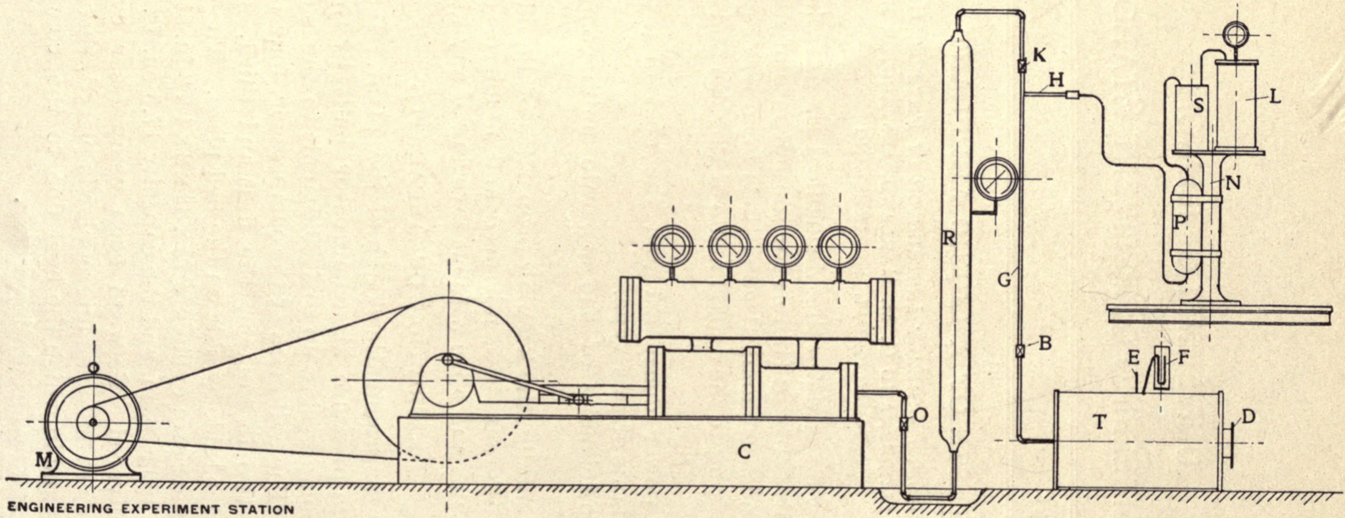

FIG. 1

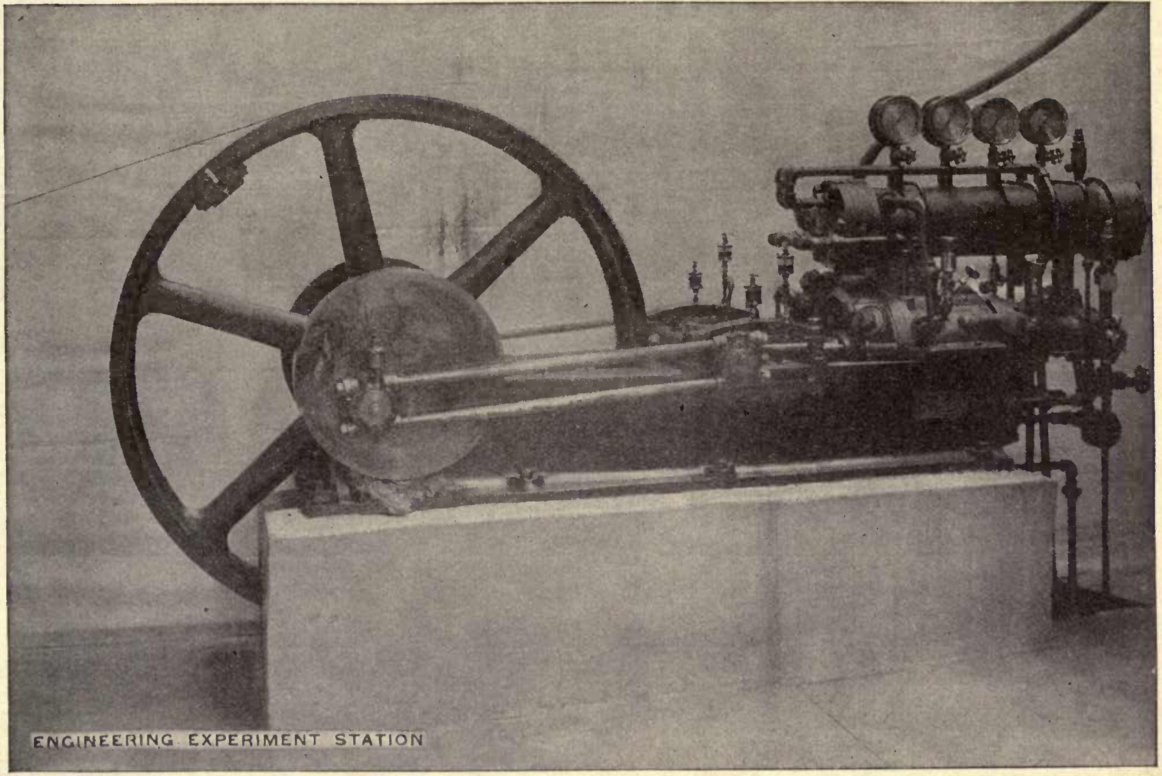

FIG. 2

The air for use in the compressor is ordinarily taken from the atmosphere above the laboratory building and drawn through a low pressure purifier consisting of a metallic can 15 in. in diameter by 36 in. in height, containing trays on which lime is spread. Owing to the small diameter of the air inlet, (one inch), and to a tendency of the lime to cake in the trays, this purifier has been found to be unsatisfactory, as it caused unnecessary suction on the compressor, thereby lowering the efficiency and also at times permitting lime dust to be drawn into the cylinder. During these tests this purifier was cut out and the air taken from the inside of the building. When the purifier was used again later, it was found that the greater part of the impurities, carbon dioxide and water, was removed by the high pressure purifier.

From the high pressure cylinder the air is conducted to the air receiver, *R*, (Fig. 1), through ½-in. extra heavy iron pipe submerged in a channel of running water. This receiver is an imported Mannesmann steel tube 12 ft. long by 9⅛ in. outside diameter, tapering to about 2 in. in diameter at the end. The thickness of the walls of this tube is about $\frac{5}{16}$ in. The tube was tested by the maker to 4000 lb. per sq. in. and may be used continuously at a working pressure of 3000 lb. per sq. in. The action of the receiver in maintaining a constant pressure of the liquefier was highly satisfactory.

A 10-in. Schaefer and Budenberg hydraulic pressure gage, graduated from 0 to 8000 lb. per sq. in. in increments of 200 lb. was used to measure the pressure in the receiver. From the receiver the air is conducted through ½-in. iron pipe, then through $\frac{5}{16}$-in. copper tubing to the high pressure purifier *P*, and from this through a coil of copper tubing of the same size fitted into an insulated cooling tank *S*, 8 in. in diameter by 20 in. deep. From this coil the air enters the liquefier *L*, the connections between coil and liquefier being made as short as possible in order to prevent the air from becoming warm in its passage.

The liquefier is the Hampson laboratory type, made by the Brin Oxygen Company of London. A sectional view of it is shown in Fig. 3 and 3*a*. The compressed air enters through the joint 36 coming directly from the coils in the precooler, and passing into the copper coils of the liquefier. As it circulates through these in succession, it is cooled more and more by the expanded air which rises around the coils, so that by the time it reaches

3000 →

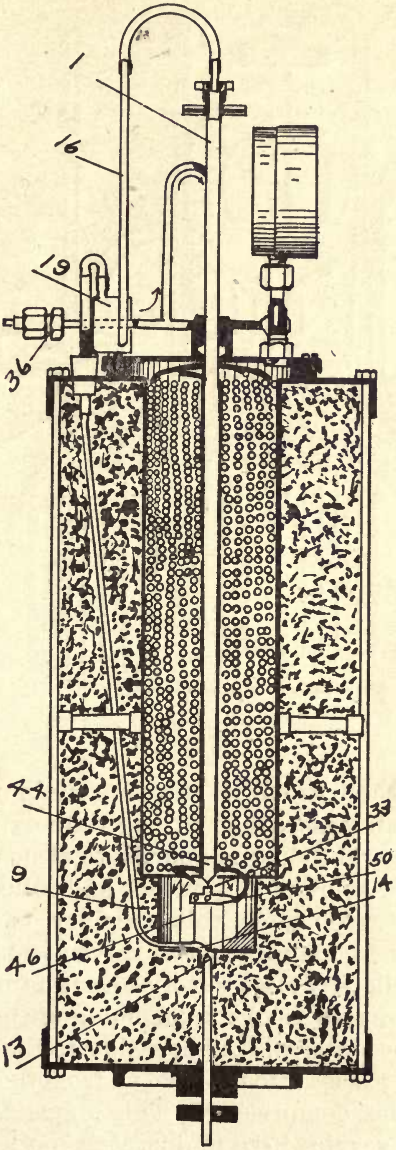

FIG. 3

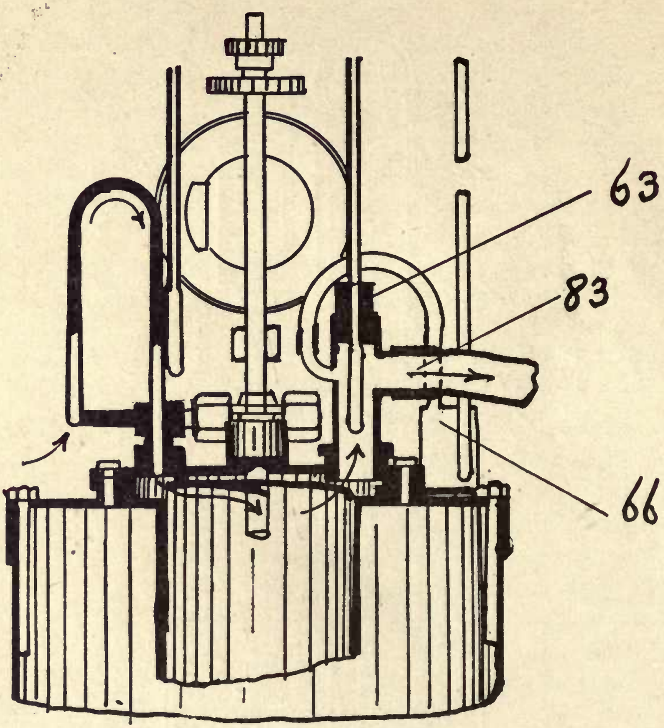

FIG. 3*a*

the lowest coil at the bottom, its temperature is near the liquefaction point. The air passes then through the expansion valve 33, dropping from several thousand pounds to atmospheric pressure, and in consequence some of it liquefies and collects in the brass receiver 46. The capacity of this receiver is about 130 cc. It can be emptied by turning the outlet valve at 14. The expanded air which did not liquefy rises slowly through the spaces between the coils and serves to cool the oncoming air inside the coils, as has been described above. After rising to the top of the coils this expanded air passes into tube 83 and from there proceeds back to the intake of the compressor. This expanded air does the greatest possible service if its temperature on leaving the space around the top coils at 83 is the same as the temperature of the entering compressed air, for in this case it has cooled the entering air as much as possible. In order to measure the temperature of

TABLE 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
No.	Receiver Pressure lb. per sq. in.	Temp. Air Entering Liq. °C.	Temp. Air Leaving Liq. °C.	Room Temp. °C.	Motor Speed r. p. m.	Compressor Speed r. p. m.	Grams of Air Liquefied per hr.	Total Wt. of Air Delivered per hr. grams	Per cent of Air Liquefied	Delivered horse power	Grams per d. h. p. hour	Pints Liquefied per hour	Cost of Power per Pint dollars	Total Cost per Pint dollars	Per cent d. h. p. Available in Liquid Air
1	2000	11	9	18	938	178	1555	33700	4.6	15.40	101.0	3.53	0.288	0.39	1.5
2	2000	19	17	16	918	173	1362	32800	4.2	15.20	89.6	3.09	0.324	0.44	1.3
3	3088	20	18	24	1130	210	2980	39600	7.5	19.74	151.0	6.77	0.192	0.24	2.3
4	3110	10	9	16	1139	211	3165	39800	8.0	19.50	162.0	7.18	0.178	0.23	2.4
5	3140	4	4	19	1129	209	3170	39400	8.0	20.0	158.5	7.20	0.183	0.23	2.4
6	3137	0	5	19	1131	210	3282	39600	8.3	20.2	164.0	7.46	0.178	0.22	2.5
7	2128	0	4	21	1137	210	2495	39800	6.3	18.2	137.0	5.67	0.213	0.27	2.1
8	1116	-2.5	4	21	1155	214	550	40200	1.3	13.8	39.8	1.25	0.728	1.01	0.6

the outgoing air, a thermometer was introduced at 63. For the incoming compressed air, however, at first a steel thermometer cup was used, introduced between the purifier and the liquefier, and the temperatures were taken by means of a mercurial thermometer. This arrangement has, however, such a large conducting surface exposed to room temperature, and the heat capacity of the air flowing through it was so small, that the air was warmed to room temperature and rendered the cooling useless. After failure with this thermometer cup, a platinum copper thermoelement was soldered into the copper tubing at the entrance to the coils, the other junction being kept in ice, and with a sensitive galvanometer the temperature of the entering air was determined within the limits of about half a degree.

THE MEASUREMENT OF THE POWER

The power to drive the compressor during these tests was supplied by a 15 h. p. Westinghouse two-phase induction motor belted direct to the compressor. The electrical input to the motor was measured by means of Weston wattmeters, one in each phase of the motor circuit. After the tests were completed and before the instruments were taken from the circuit, a brake horsepower test was run on the motor. Two sets of readings were taken, one set as the load was applied, the other set as the load was taken off. Table No. 1*a* shows the results of this test. The ratio of the brake horsepower to the kilowatt input was found to be practically constant for loads from ⅝ to 20 per cent overload. This ratio 0.77 was used in calculating the horsepower delivered to the compressor. This method for obtaining the delivered horsepower (d. h. p.) was used for the reason that it was impossible to calibrate the instruments in the time at our disposal.

The speed of the motor was taken by a hand counter. The compressor, as before stated, was driven by a belt from the motor. The speed of the compressor for several tests was taken by means of a mechanical counter; this, however, became unreliable, so that in the calculation of the results the speed of the compressor was calculated from the speed of the motor, there being practically no slippage of the belt.

All tests with the exception of one were of two hours' duration. Readings were taken every ten minutes. The power as given in Table No. 1, column 11, is accurate within about 3½ per cent.

TABLE 1*a*

	Up	Down	Up	Down		Up	Down		
Weight on Scales pounds	Speed r. p. m.	Speed r. p. m.	Kilowatts	Kilowatts	Kilowatts Average	B. H. P.	B. H. P.	B. H. P. Average	Ratio Kw. to B. H. P.
0		1183		.8	.8				
5		1190		2.4	2.4		2.83	2.83	
10	1162	1176	3.8	3.8	3.8	5.53	5.60	5.56	
15	1153	1157	6.4	6.4	6.4	8.23	8.26	8.24	
20	1165	1140	8.4	8.4	8.4	11.09	10.85	10.97	.7650
25	1126	1135	10.4	10.4	10.4	13.40	13.51	13.45	.7738
30	1117	1126	12.2	12.2	12.2	15.95	16.08	16.01	.7624
35	1100	1100	14.4	14.8	14.6	18.33	18.33	18.33	.7963
40	1092	1082	16.0	16.2	16.1	20.80	20.60	20.70	.7780
45	1030	1030	19.2	19.2	19.2	22.16	22.06	22.06	

THE MEASUREMENT OF THE AIR USED

The measurement of the amount of air delivered by the compressor was made by means of a thin plate orifice, the necessary data being obtained from an article by Mr. R. J. Durley in the *Transactions of the American Society of Mechanical Engineers, Vol. 27.* This method is as follows: Referring to Fig. 1, *G* is a pipe line leading from the high pressure air receiver; *H* is a connection to the liquefier; *K* and *B* are special heavy globe valves; *T* is a sheet iron tank connected at one end with the half-inch pipe leading from the receiver; the opposite end of this tank is fitted at *D* with a thin plate orifice one inch in diameter, cut from a plate of 0.0571 in. thickness. *E* and *F* are respectively thermometer and U-tube for measuring the temperature and pressure in the tank *T*. During the regular tests on the liquefier, the valve at *B* remained closed. After each test was completed, a short test was run under the same conditions of compressor speed and receiver pressure in order to determine the amount of air used, the pressure being maintained constant in the receiver by slightly opening the valve *B* and allowing the compressed air to expand into the tank *T* and escape through the orifice at *D*. The data recorded in these tests were the pressure in inches of water in the tank and the temperature. With these data was obtained the flow of air in the tank in pounds per second from the work of Mr. Durley as referred to above.

On looking over these tests to determine the amount of air used, it was seen that some of the results were not consistent. The discrepancy was due to the difficulty in throttling the air by means of the valve *B*, to the short period of the test (ten minutes), and to the fact that the pressure in the receiver varies very slowly when the escaping air has been throttled close to the proper amount necessary for the maintenance of the constant pressure. Owing to these causes and also to a desire to obtain the efficiency of the compressor, a series of tests was run on the compressor and the amount of air delivered measured in the same manner as above described. These tests were, however, from 30 to 45 minutes' duration, thus giving plenty of time for the pressure in the receiver to vary. If it was found that the pressure was slowly increasing or decreasing, the valve *B* was adjusted and the test was run over again. These tests, six in number, were run with pressures of approximately 1000, 2000 and 3000 lb. per sq. in. in the receiver, and with an average speed of the compressor in the first set of 200 revolutions per minute, and in the second set, of about 184 revolutions. From the results of these tests Table 2 was computed.

It will be seen from the table that the first set of tests was run at speeds of about ten per cent lower than the speeds during the regular tests on the liquefier. This was due to low voltage on the line supplying power to the motor. In order to correct for this difference in speed in calculating the amount of air supplied to the liquefier and also in calculating the per cent of air used by the liquefier, it was assumed that the air delivered was directly proportional to the speed of the compressor. This, of course, is not exactly cor-

TABLE 2

EFFICIENCY TESTS OF AIR COMPRESSOR

	Receiver Pressure	Motor Speed r. p. m.	Compressor Speed r. p. m.	Delivered horse power	Air Delivered by Compressor lb. per min.	Free Air Delivered Cu. ft. per min. at 60° F.	Mechanical Efficiency	Th'r't'c'l h. p. for Isothermal Compression	Efficiency of Compression
TEST NO. 1									
1	1058	1074	198	14.4	1.380	18.13	58	5.06	61
2	2043	1084	200	18.2	1.392	18.29	66	5.90	50
3	3007	1081	200	19.9	1.386	18.21	99	6.24	45
FRICTION TEST OF AIR COMPRESSOR									
1	0	1145	212	6.5=Friction h. p.					
TEST NO. 2									
1	3100	1094	179	17.7	1.23	16.16	67.5	5.66	47
2	2100	1128	184	15.7	1.23	16.35	62.0	5.25	54
3	1000	1135	186	13.9	1.26	16.75	57.0	4.57	58
FRICTION TEST									
1	0	1172	192	6.18=Friction h. p.					

rect; the total error introduced, however, is quite small, and as the figures resulting from this assumption are not used in any calculations of importance, the assumption is justified.

The second set of compressor tests was run at a speed of about 184 r. p. m., obtained by changing the motor pulley. This set of tests was made in order to determine the effect of speed on the efficiency of the compressor.

It will be observed from Table 1 that the speed of the compressor during the regular tests was about 16 per cent higher than the rated speed. It was thought desirable at the beginning of these tests to run at this speed in order to operate the liquefier close to its capacity. It will be noted from Table 2 that the efficiency of the compressor falls off slightly with increasing speed, as is to be expected. This small loss in compressor efficiency is probably compensated, however, by increased efficiency of the liquefier at higher capacities.

In Table 2 will also be found the results of friction tests run on the compressor at the two speeds. The friction is practically constant and is therefore proportional to the speed. This was assumed in calculating the efficiency of the compressor, as the speeds varied somewhat owing to fluctuations in the line voltage. These friction tests were run directly after the respective compressor tests with the air inlets to the different cylinders broken so that the air was under no compression in the cylinders.

The mechanical efficiency was obtained from the formula,

$$\text{Mechanical Efficiency} = \frac{\text{Delivered h. p.} - \text{Friction h. p.}}{\text{Delivered h. p.}}$$

The theoretical work was obtained by calculating the work of isothermal compression for the weight of *air delivered* at the pressure in the receiver. The efficiency of compression was calculated as,

$$\text{Efficiency compression} = \frac{\text{Theoretical work done}}{\text{Delivered h. p.} - \text{Friction h. p.}}$$

and it was found to decrease with increase of pressure as was to be expected.

The amount of air delivered by the compressor as given in Table No. 2 is probably accurate within 2 per cent.

COLLECTING AND MEASURING THE AIR LIQUEFIED

At the beginning of the test, before the pressure had risen above 1000 lb., the expansion valve of the liquefier was opened for several minutes in order to dry out the interior of the coils and to blow out whatever oil and dust had collected in them. A few drops of oil invariably came through the open outlet valve during this cleaning. The expansion valve was then closed, not to be opened again until the full pressure of the tests, 1000, 2000 or 3000 lb. was reached.

After the establishment of the desired pressure for the test, the expansion valve was again opened and the time noted which elapsed before the first drops of liquid air appeared. This interval of time is very different for the different pressures and is an important factor to be considered whenever liquid air must be quickly obtained. In the accompanying Table 3 the time necessary for the cooling from room temperature to that of liquefaction is given for the range of pressures that these tests cover.

TABLE 3

Pressure pounds	Minutes required for liquefaction
1000	14.0
2000	6.0
3000	1.5

It is evident from the above table that if the pressure were reduced much below 1000 lb. the cooling would take place so slowly that no liquid air would be produced. Facts that will be given later in this article show that the lowest possible pressure at which the liquefier will yield liquid air appears to be about 900 lb.

After the liquid had begun to flow at a uniform rate, the observations of the tests were begun. The air was collected in silvered Dewar bulbs of two liters capacity, which were mounted on a platform balance directly under the outlet tube of the liquefier, which extended about an inch down the neck of the bulb. Although there is considerable evaporation from the stream of liquid air which flows from the outlet tube into the bulb, it seems impossible to prevent this loss by any simple and practical device. An attempt was made to reduce it as much as possible by making the outlet tube extend well inside the neck of the Dewar bulb. As this loss is inherent in the practical operation of this liquefier, it was thought best to charge it to the efficiency of the liquefier.

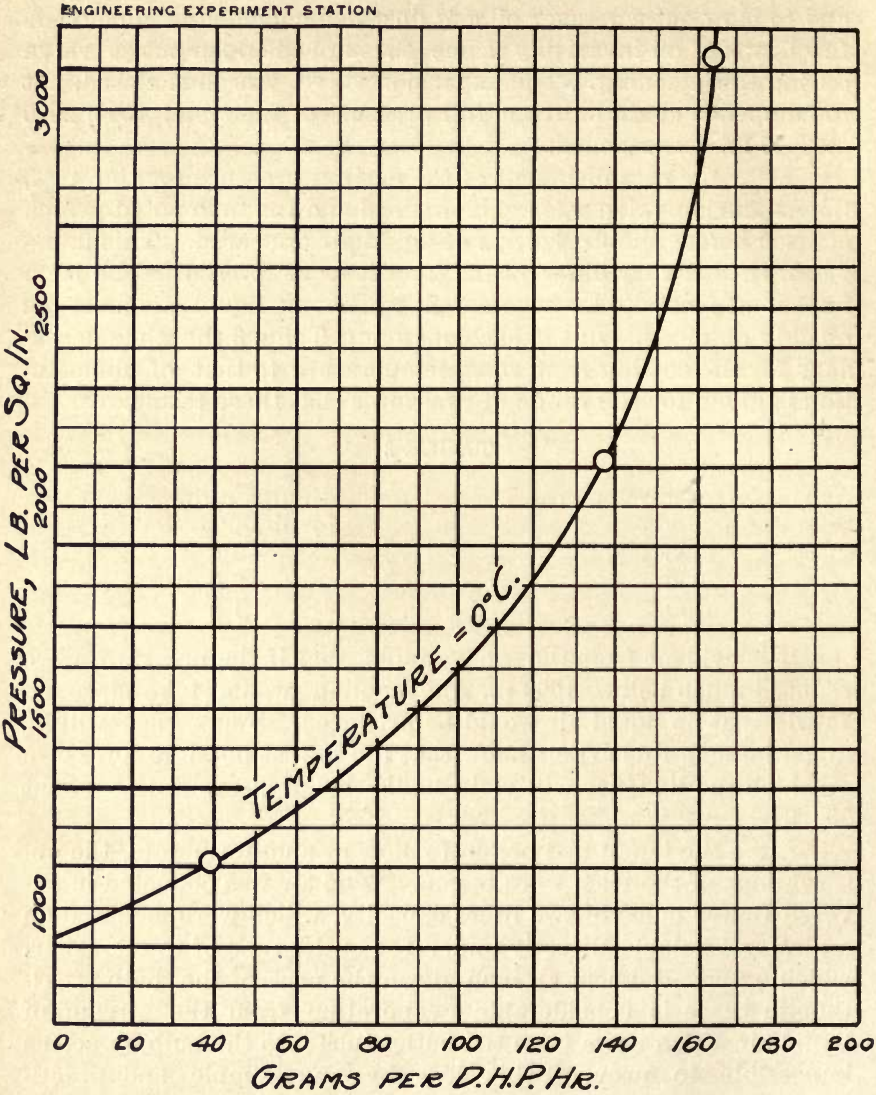
ENGINEERING EXPERIMENT STATION
PRESSURE, LB. PER SQ. IN.
3000
2500
2000
1500
1000
TEMPERATURE = 0°C.
0
20
40
60
80
100
120
140
160
180
200
GRAMS PER D.H.P. HR.

FIG. 4

The liquid which collected in the bulb was weighed at intervals of ten minutes, and the rate of production was found to be very uniform. The outlet valve was opened at intervals of about a minute during fifteen seconds in order that the liquid might run out in a full fast stream, and thus experience less loss from evaporation than if the outlet had been open continuously and the stream had been small in consequence.

The expansion valve was opened just enough so that the flow of air through it kept the pressure of the receiver down to the constant pressure of the test. It required only occasional regulation. Only twice during the eight tests did any trouble occur which was traceable to the liquefier. Once when the operator neglected to discharge the liquid air from the outlet chamber often enough it rose into the glycerine pressure gage and froze and burst the rubber tubing connection, necessitating the closing of that test twenty minutes short of the usual two hours' duration. At another time the liquefier became clogged from accumulated dirt, water and grease and had to be taken apart and all the valves thoroughly cleaned with a jet of steam. It should be stated, however, that this was the first cleaning that the liquefier had needed during its intermittent but rather hard service of eighteen months.

INFLUENCE OF PRESSURE ON THE EFFICIENCY OF THE LIQUEFIER

In Fig. 4 is shown the relation between the working pressure and the quantity of air liquefied per horsepower hour, taken from tests No. 6, 7 and 8 of Table 1, all of which were conducted at or near 0° C. It is clear from the curve that the efficiency is greater the higher the pressure. It is also evident that the efficiency would become zero, i. e., that no liquefaction would take place, at a pressure of approximately 900 lb. per sq. in. Also, increase of pressure at high pressures causes a smaller increase in efficiency than does the same increase in pressure at low pressures. This last conclusion shows that it is not desirable to increase the working pressure much over 2500 lb. per sq. in. in producing liquid air with this liquefier, for the reason that only a small gain in efficiency is thereby obtained, and this at a cost of a very considerable increase in the trouble and danger attendant upon the maintaining of high pressures in the plant. The numerous connections and valves of the plant must be continually inspected in order to prevent serious leaks when the pressure is 3000 lb., but at lower pressures there is little difficulty in this respect.

Our results regarding the influence of pressure on the efficiency of the liquefier agree with the conclusions of other experimenters of this general type of liquefier. Others[1] have, however, found that the lowest pressure at which liquefaction occurs is about 700 lb.

INFLUENCE OF TEMPERATURE ON THE EFFICIENCY OF THE LIQUEFIER

The temperature of the air as it enters the coils of the liquefier has an important influence on the efficiency of the liquefier, the lower the temperature the greater being the efficiency. We have measured the influence of temperature over a range between 0° and 20° C. for two pressures, namely 2000 and 3000 lb. per. sq. in., and the data are given in Table 1 under tests 1 to 7 inclusive. In the accompanying Fig. 5 these results are plotted. The curves for the two pressures closely approximate straight lines. If the inlet temperature were below 0 the efficiency would be correspondingly greater and the cost of production less; but it does not seem advisable in intermittent operation of the plant to reduce the temperature of the entering air below 0, as the trouble and labor necessary to keep a freezing mixture of salt and ice in the precooler more than balance the gain in efficiency. Indeed, if cold tap water of a temperature of about 15° is allowed to run through the precooling tank, the efficiency at 2500 lb. is almost as great as would be obtained ordinarily when cracked ice is placed in the tank. The reason for this apparent contradiction is that unless the ice is continuously stirred, the water next to the cooling coils becomes warmed much above 0° C., but if running water flows through the tank its motion keeps cold water near the coils. The temperature of the coil is, therefore, not much different whether unstirred ice or running tap water is used; the latter method of cooling, however, is more convenient and less expensive. In our tests at 0° C. a mixture of ice and salt was used, being stirred every five minutes; the temperature of the air was not reduced much below 0° C. and in all cases it was directly measured by the thermojunction at the entrance to the liquefier.

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[1] Bradley and Rowe, Physical Review, Vol. 19, 1904, p. 330.

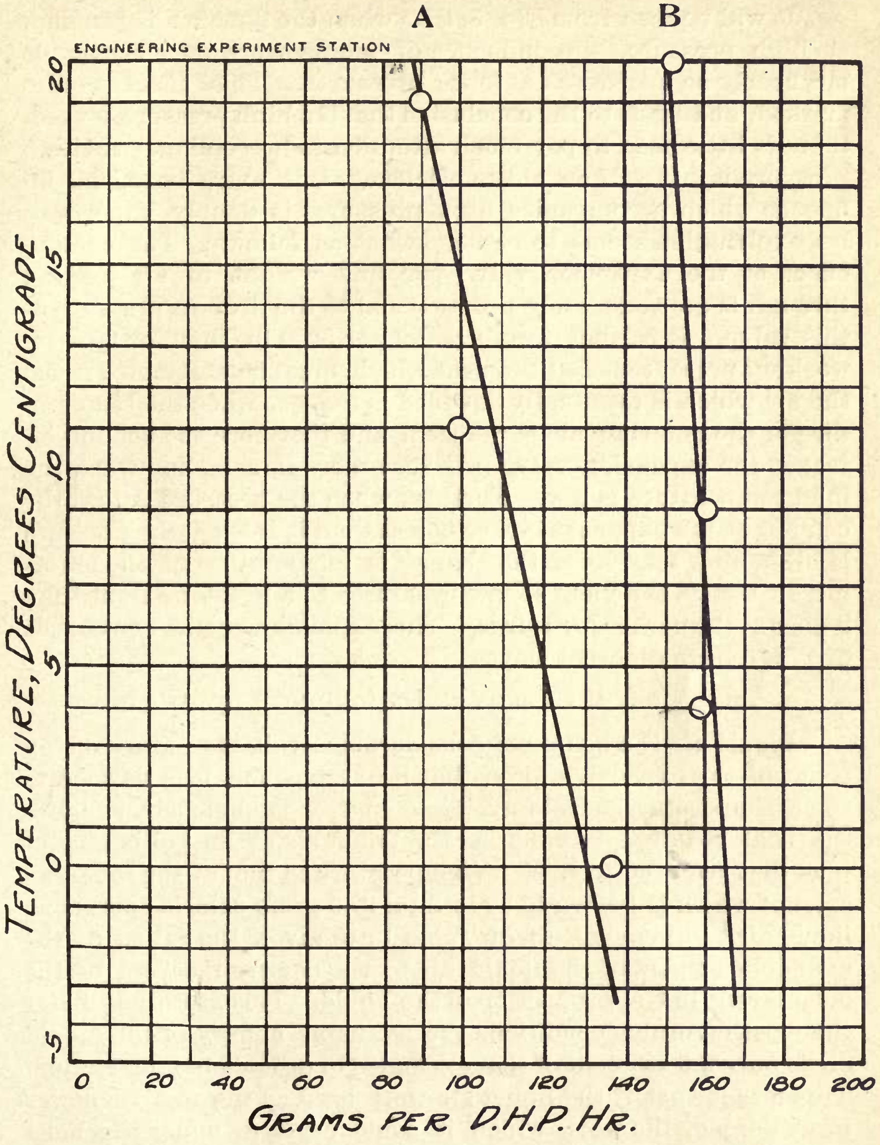

FIG. 5

A = 2000 lb. per sq. in.
B = 3000 lb. per sq. in.

It will be seen from Fig. 5, that when the liquefier is working at high pressure, the influence of temperature on efficiency is not nearly so marked as at lower pressures. This effect is quite marked, and leads to the conclusion that if a high pressure is used, there is little need to pay much attention to precooling. As high pressure is of itself an aid to efficiency, this extra beneficial influence which accompanies high pressures is doubly important. Its explanation seems to be somewhat as follows: The cooling effect at the expansion valve per unit weight of air passing through is approximately proportional to the drop in pressure at this valve. It is, therefore, greater for 3000 lb. than for 2000 lb. working pressure. But the heat which must be abstracted from the air which is eventually liquefied is reduced when the temperature of the entering air is reduced, and therefore the cooling effect at the expansion valve produces more liquefaction when the inlet temperature is low. Further, when the pressure is low, the cooling at the expansion valve is less than it is when the pressure is high, and, therefore, the change in temperature of the entering air affects the yield at low pressures to a greater extent than it does at the higher pressures. This explains why the two curves of Fig. 5 have different slopes.

THE LOSS OF ENERGY IN PRODUCING LIQUID AIR

Liquid air is a source of considerable available energy on account of the expansive force that it exerts when it is warmed to room temperature. This available energy is obviously equal to the heat required to vaporize the liquid air at its boiling point plus that required to raise its temperature to that of the room; an amount which is known to be in total 97.5 gram calories per gram liquid air.[1] In column 16 of Table 1 are given the ratios of the available energy of the liquid air to the energy received by the compressor in the production of the liquid. It is seen that under the most favorable conditions the available energy of the liquid air is only 2.5 per cent of that expended in producing liquefaction. This means that if the liquid air were used as the motive power in an engine, the work which it could perform under the most favorable conditions is only 2½ per cent of the work which was required to produce the liquid air. It is thus very clear that liquid air is wholly unsuited to the storage or transfer of power.

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[1] Allen and Ambler, *Physical Review*, Vol. 15, p. 183, 1902.

The Keeping of Liquid Air in Dewar Bulbs

A few tests were made in order to learn the approximate rate of evaporation of liquid air from Dewar vacuum bulbs under varying conditions of size of bulb, presence of felt coverings, and silvering of the bulb. Previous experimenters have found that similar bulbs show very different behavior, probably caused by the varying of the thickness of the silvering, which is a good metallic conductor, and the different degrees of exhaustion and heat conductivity of the glass bulbs.

Regarding the influence of the size of the bulb on the rate of evaporation, no important difference was noted between the proportionate loss from two silvered bulbs, one of a liter capacity and half filled, the other of a quarter liter capacity and filled; both flasks lost one quarter of their liquid air in 24 hours when exposed to the temperature of 20° C. unprotected by any coverings. Covering the bulb with felt diminished the loss by evaporation, for a silvered liter flask containing at the start 900 grams of liquid air was found to preserve 100 grams after standing four days in its felt-lined basket, which is a rate of loss somewhat less than that for the uncovered flasks.

But a most noticeable aid in the protection of the air from evaporation comes from the silvering of the bulbs, which reflects light and radiant heat that would otherwise be absorbed by the bulb and its contents. The loss from unsilvered but evacuated bulbs is so great that a boiling of the liquid air in them can be seen, whereas the silvered bulbs show a quiet surface when viewed through the mouth of the bulb. In an experiment on two similar liter bulbs, one of which was silvered, the other not, it was found that after standing 24 hours all of the half liter of air in the unsilvered bulb had evaporated, but only 100 grams of the half liter in the silvered bulb.

The Cost of Producing Liquid Air

In columns 14 and 15 of Table 1, is given the cost of production of liquid air as given by these tests. The only expenses which are here included are the cost of the power used, estimated at eight cents per kilowatt hour, and the cost of an attendant, reckoned at thirty-five cents per hour.

When the plant is running at 3000 lb. pressure and the temperature of the air entering the liquefier is 0° C., conditions which give the greatest efficiency that we have obtained, the total cost of the liquid air, including both the cost of the power and of the operator's services, is 22 cents per pint. When the plant is running at 15° C. and 2500 lb. pressure, which are the most convenient conditions of temperature and pressure, the total cost is about 32 cents.

PUBLICATIONS OF THE ENGINEERING EXPERIMENT STATION

Bulletin No. 1. Tests of Reinforced Concrete Beams, by Arthur N. Talbot. 1904. (*Out of print*).

Circular No. 1. High Speed Tool Steels, by L. P. Breckenridge. 1905.

Bulletin No. 2. Tests of High-Speed Tool Steels on Cast Iron, by L. P. Breckenridge and Henry B. Dirks. 1905.

Circular No. 2. Drainage of Earth Roads, by Ira O. Baker. 1906.

Bulletin No. 3. The Engineering Experiment Station of the University of Illinois, by L. P. Breckenridge. 1906. (*Out of print*).

Bulletin No. 4. Tests of Reinforced Concrete Beams, Series of 1905, by Arthur N. Talbot. 1906.

Bulletin No. 5. Resistance of Tubes to Collapse, by Albert P. Carman. 1906. (*Out of print*).

Bulletin No. 6. Holding Power of Railroad Spikes, by Roy I. Webber. 1906.

Bulletin No. 7. Fuel Tests with Illinois Coals, by L. P. Breckenridge, S. W. Parr and Henry B. Dirks. 1906.

Bulletin No. 8. Tests of Concrete: I. Shear; II. Bond, by Arthur N. Talbot 1906. (*Out of print*).

Bulletin No. 9. An Extension of the Dewey Decimal System of Classification Applied to the Engineering Industries, by L. P. Breckenridge and G. A. Goodenough. 1906.

Bulletin No. 10. Tests of Plain and Reinforced Concrete Columns, Series of 1906, by Arthur N. Talbot, 1907.

Bulletin No. 11. The Effect of Scale on the Transmission of Heat through Locomotive Boiler Tubes, by Edward C. Schmidt and John M. Snodgrass. 1907. (*Out of print*).

Bulletin No. 12. Tests of Reinforced Concrete T-beams, Series of 1906, by Arthur N. Talbot. 1907.

Bulletin No. 13. An Extension of the Dewey Decimal System of Classification Applied to Architecture and Building, by N. Clifford Ricker. 1907.

Bulletin No. 14. Tests of Reinforced Concrete Beams, Series of 1906, by Arthur N. Talbot. 1907.

Bulletin No. 15. How to Burn Illinois Coal without Smoke, by L. P. Breckenridge. 1908.

Bulletin No. 16. A Study of Roof Trusses, by N. Clifford Ricker. 1908,

Bulletin No. 17. The Weathering of Coal, by S. W. Parr, N. D. Hamilton. and W. F. Wheeler. 1908.

Bulletin No. 18. The Strength of Chain Links, by G. A. Goodenough. 1908.

Bulletin No. 19. Comparative Tests of Carbon, Metallized Carbon and Tantalum Filament Lamps, by Thomas H. Amrine. 1908.

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Bulletin No. 21. Tests of a Liquid Air Plant, by C. S. Hudson and C. M. Garland. 1908.

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